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ASPECTS OF COGNITIVE REPRESENTATION: EXAMINATION OF THE 'MENTAL ROTATION' PARADIGM

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled Aspects of Cognitive Representation: Examination of the 'Mental rotation' Paradigm submitted by Michael William Katzko in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

For my parents

ABSTRACT

This dissertation examines the extent to which data collected in the 'mental rotation' paradigm can be said to be supportive of the mental rotation hypothesis. It is argued that accepting such data as strong support for the hypothesis entails holding at least three additional assumptions about the nature of the cognitive processing involved. These are (1) that absolute angular disparity is the main functional property of the stimulus which the process operates on, (2) that there is just one process which mediates changes in response latency as a function of angular disparity, and (3) that the functional properties of this process are invariant across magnitude changes in angular disparity.

An examination of the empirical literature suggests that each of these assumptions is of doubtful validity. In particular, the assumption regarding the functionally important stimulus property is challenged. It is shown that a notion of a co-ordinate frame of reference is required to account for some aspects of task performance. Two experiments are reported which demonstrate the significant effect which a pattern, unambiguously oriented in a gravitation al co-ordinate frame, has on response latency. Specifically, it serves to eliminate the increasing linear relationship between response latency and angular disparity at disparities greater than 90°. To account for this finding, the 'rotation' hypothesis is abandoned in favour of

a model which incorporates a gravitationally defined co-ordinate frame for determining the orientation of the patterns during task performance.

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INTRODUCTION

Within the current controversy over the nature of cognitive representation there is a body of data which is judged supportive of theoretical claims made by the imagery-analog position. These data are produced by the 'mental rotation' paradigm developed by Shepard and his associates (see Shepard, 1975, for a review). As first reported by Shepard & Metzler (1971), and expanded by Metzler & Shepard (1974), it was found that "the time required to determine that two perspective pictures portray objects of the same three-dimensional shape increases according to a strikingly linear function of the angular difference in the portrayed orientations of the two objects" (Metzler & Shepard, 1974, p. 168). That is, the obtained data can be described by the equation

$$RT = a + bA. \tag{1}$$

Here, $\underline{RT}$ is the response latency, $\underline{A}$ is the angular disparity, $\underline{a}$ is the intercept and $\underline{b}$ is the slope. The interpretation of this function, i.e., a theoretical account of the cognitive activity which produces this result, was as follows: "the subject makes the determination of sameness of shape by carrying out some sort of analog of an external rotation of one object into congruence with the other" (p. 168).

This analogy to a physical process is, on the surface, appealing for two reasons. The mathematical formalism which expresses the relationship between motion and distance for physical objects also fits the linear relationship described in equation 1. Given that an object is travelling at a constant velocity, $\underline{v}$, the time travelled, $\underline{t}$, will be a linear function of the distance travelled, $\underline{d}$. Thus, we have the following equation in the physical model

$$t = d/v. \tag{2}$$

In this case, the reciprocal of the slope indicates velocity, and the intercept is an additive constant which does not enter into the causal relationship between time, velocity, and distance.

In addition to the quantitative data, described in the above fashion, there was also a more subjective, or qualitative set of data. These data comprise not only subjects' reports of visual imagery but also the reports which suggest that the images were 'rotated'. The suggestive parallel was that such a description -- that of a rotation of an object -- can also be applied to a physical movement of a real object. This characterization of task performance as a 'mental rotation' of one representation into congruence with another has been viewed as supportive of a more general image-analog view of cognitive representation (e.g., Anderson & Bower, 1973; Attneave, 1974; Chase, 1978; Crowder, 1976; Kosslyn, Pinker, Smith, & Shwartz, 1979; Kosslyn & Pomerantz, 1977; Paivio, 1978).

The purpose of this dissertation is to examine the

validity of this conclusion. Two general questions will be raised. First, to what extent can the existing data collected within the 'mental rotation' paradigm be reasonably considered to be evidence for the rotation hypothesis? Second, is the 'rotation' hypothesis, independent of immediate supporting evidence, worth retaining as a working assumption about the nature of cognitive functioning and representation?

The first question aims at exploring the relationship between a data structure and a cognitive model derived from it. Specifically, it shall be argued that accepting the above described linear function as evidence entails holding certain assumptions about the cognitive activity which underlies task performance. The assumptions to be considered here are extensions of three characteristics of equation 1. These are: (1) the number of variables in the equation, (2) the number of parameters in the equation, and (3) the relationship between the parameters and the variables. Each of these shall now be discussed in turn.

As expressed in equation 1, there is only one variable which a model must take account of. Taken literally, the equation suggests

> (A1) Angular disparity between two patterns is the major stimulus variable which the psychological process takes account of when judging the similarity of two patterns.

This assumption is supported by an analogy to the physical model. The physical model in equation 2 asserts that

considerations of the properties of the object do not enter into the causal relationship between time, distance, and velocity. Translated into psychological terms, this suggests that intrinsic structural characteristics of the patterns are not in any important way related to the process of judging the similarity of patterns rotated relative to each other.

This assumption can lead to a number of additional claims. For example, one possible extension is that the process operates uniformly on the entire or whole representation of the pattern. This would appear to make sense, given the physical analogy and the subjective reports. In addition, the assumption has led to additional claims that the representation is therefore image- or picture-like, presumably by stressing the phenomenal characteristics of the mental experience. However, if one holds strictly to the analogy, there is no way in which strong inferences can be made regarding the representation, as these data do not directly address that question. At best, conclusions regarding cognitive representation are totally dependent on the requirements of the hypothesized psychological process which mediates the experimental variables.

The major theoretical task which confronts the psychologist involves interpreting the structure of the data to determine what it tells us about the underlying cognitive activity. If equation 1 is viewed as indicating a process model of the psychological relationship between the

experimental variables, then the parameters can be interpreted as reflecting the functioning of cognitive processes. That is, the problem of interpretation involves determining the relationship which the parameters of the equation have to hypothesized psychological variables which cause the observed relationship.

In equation 1 the slope and the intercept are the two parameters which require interpretation. Literally, the slope simply defines the change relationship between the two experimental variables <u>RT</u> and <u>A</u>. If taken as indicating a cognitive process, it is central to the theoretical explanation because it is the functioning of this process which causes the observed relationship between <u>RT</u> and <u>A</u>. Since the intercept in the 'mental rotation' studies is positive and non-zero, it is appropriate to assume the existence and operation of other psychological processes. If one maintains the analogy to the physical model, then the intercept is interpreted as follows: whatever else might be happening psychologically, over and above a mental 'rotation', is considered to be unaffected by variations in the value of <u>A</u>. Taken together, then,

(A2) There is one process which mediates the effect of angular disparity on the time taken to judge the similarity of two patterns.

Stated in this way, the slope indicates whatever is causally central to a theoretical account of the data in question. One possible interpretation of the slope can be referred to as the <u>continuous rotation model</u>, commonly known

as the imagery or analog interpretation of mental rotation. By substituting directly into equation 2 the appropriate variables characterizing the psychological event we have

$$RT = A/m. \tag{3}$$

As stated above, m corresponds to velocity in the physical model. Analogously, m corresponds to a single psychological variable. The 'rate' is presumed to imply a 'continuous' or 'analog' quality to this underlying psychological variable.

A second alternative might be called the finite iterative model, which was described by Cooper & Shepard (1973) and by Metzler & Shepard (1974). They suggested a process which incrementally transforms the representation of one pattern into the other. The intermediary positions were presumed to stand in a one-to-one relationship with the intermediary positions of an actual rotation of a physical object, and in view of this, the process was considered to be functionally analogous to a physical rotation. Cooper & Shepard (1973, p. 160) are quite clear on this point:

> We are not claiming that the "mental rotation" was analogous to a corresponding physical rotation to the extent of being strictly continuous. Quite possibly the rotation was carried out as a sequence of discrete steps... Such a step would not itself be an analog process since, by hypothesis, intermediate stages of its process would not have the required one-to-one relation to external orientations. However the entire rotation, composed of several such steps, would

still qualify as an analog process in the important sense that, again by hypothesis, it has intermediate states (albeit only a finite number) that have the required one-to-one relationship.

The 'linearity' of the relationship between _A_ and _RT_ is thus not an indication of an analog-like continuity, but rather is an indication of the number of iterations required.

This formulation suggests a quantity, _r_, which indicates the duration of a single iteration. In addition, there must be some quantity, _i_, which is the size of the angular increment of one iteration. The number of iterations will be given by A/i and _RT_ will thus be given by _r_ multiples of this quantity. The relationship is given by

$$RT = (r/i)A. \qquad (4)$$

What is being indicated here is the belief that the psychological unknown designated by the slope of the equation is actually comprised of at least two psychological variables. Although the _finite iterative model_ admits of more than one _variable_, this is irrelevant to the causal assumption. As Cooper & Shepard (1973) indicate, they are making no claims as to the detailed structure of this process and how it produces outputs. The set of variables can be viewed as a functional system, not unlike the OPERATE phase of a TOTE unit (Miller, Galanter & Pribram, 1960).

The empirical difference between the two models, given assumption A2, is as follows. The slope provides a direct measure of the single psychological variable hypothesized by the continuous rotation model. 'Rate' is thus viewed as a

rate of functioning of this variable. In contrast, there is a problem in the lack of correspondence between the number of parameters in the data description and the number of hypothesized psychological variables in _finite iterative model_. Because of this, and in the absence of further information, the values of _r_ and _i_ cannot be extracted from an examination of the slope value. The notion of a 'rate' applies only to the empirically determined 'rate of change' of _RT_ as a function of _A_.

Another processing assumption is based on the view that the linearity of the data function constitutes the main quantitative evidence for the hypothesized models. The presence of a _linear_ relationship between _RT_ and _A_ implies a number of claims which can be made about the underlying cognitive processing. As Metzler and Shepard argue, the linearity implies an additive process: going from point A to point B necessarily involves going through a subset of the intermediate points. If this is the case, then

(A3) The nature of the process engaged in task performance is invariant across changes in angular disparity.

Stated in another way, what a person does when the patterns are at at a 30° angular disparity is exactly the same as what a person does when the patterns are at a 140° angular disparity. This also implies that the values of the parameters are constant. Or, in terms of the two psychological models: in the _continuous rotation model_ the 'rate of rotation' is constant, and in the _finite iterative_

model the angular increment and the time to make one iteration are both constant, or independent of absolute angular disparity.

An Empirical Evaluation

We now examine in greater detail some of the empirical data relevant to an evaluation of these assumptions. Unfortunately, the research has tended to be somewhat nonsystematic in terms of explicitly testing aspects of the above models and their assumptions. In view of this, what shall be done instead is to examine the extent to which the data which was used as the basis for the original interpretatons have been replicated in other studies.

Assumption A3

The existence of a linear function has been considered primary evidence for the two rotation models discussed here. A non-linear function has been found in studies using stimulus materials such as letters (Cooper & Shepard, 1973) and drawings of left and right hands (Cooper & Shepard, 1975). Cooper & Shepard (1973) concluded that "the finding of a consistently nonlinear relation between reaction time and orientation of test stimulus here does not weigh against the hypothesis that subjects typically used mental rotation to determine whether an inverted test stimulus was normal or backward" (p. 124). Perhaps, but the critical phrase is "does not weigh against". The data may not disprove the rotation hypothesis in either of its forms, but the

nonlinearity must nonetheless be accounted for, and in a way which does not violate the assumptions of the model. For example, the nonlinearity might be due to some process other than a mental rotation, but this would violate assumption A2. Naturally, Cooper & Shepard see this possibility as unlikely. This is because there would no longer be an unequivocal relationship between the observed data and the hypothesized mediating psychological variables. If it is possible for a nonlinear function to be due to two or more cognitive processes then, by the same argument, the original linear data may be due to any combination of variables, changing linearly or otherwise as a function of angular disparity.

Another possibility which Cooper & Shepard suggest is that the nonlinearity is due to the unique characteristics of the stimuli used in that study (alpha-numeric characters). There are two difficulties with this suggestion. In the first place, it casts a shadow over the validity of assumption A1, to which we shall turn shortly. In the second place, data subsequently collected by Just and Carpenter (1976), who used the same stimulus objects as Metzler & Shepard (1974), showed that response latencies increased monotonically with increased angular disparity. However, the increase was linear only up to about 100°, after which the response curves were positively accelerated. This _may_ be due to lack of practice, but it must be kept in mind that these qualifications simply serve to introduce additional variables into the problem.

Finally, Cooper & Shepard suggested one might compare patterns within a given range of angular disparity without recourse to a rotation transformation, and that beyond this range, a rotation is required. Assuming individual differences in the value of this range, then the nonlinearity might be an averaging artifact. However, the notion of averaging artifact as a valid explanation of data can cut both ways. It can account not only for unwanted nonlinearity but also for the linearity which supports their model.

As an alternate approach to the type of defense presented by Cooper & Shepard, it might be worthwhile to abandon the idea that a linear function constitutes evidence for the model's veridicality. Reconsider equation 4 in the light of the last explanation for nonlinearity considered by Cooper & Shepard (1973) mentioned above. Specifically, they suggested that within some range of angular disparity a 'rotation' might not be required. It has already been pointed out that this notion is implicit in the <u>finite iterative model</u> and corresponds to $\underline{i}$ in equation 4. We shall again assume that all variables are constant except for $\underline{A}$, the angular disparity. As long as $\underline{A} < \underline{i}$, <u>RT</u> will be constant. When $\underline{i} < \underline{A} < 2\underline{i}$ there will be one additional iteration and so forth for greater values of $\underline{A}$. This suggests that the <u>RT</u> function predicted from the <u>finite iterative model</u> should consist of $\underline{A}/\underline{i}$ plateau regions (rounded up to the nearest whole number) with a plateau width equal to $\underline{i}$.

Admittedly, this places the <u>finite iterative model</u> in the curious position of not being supported by the data for which it was developed to interpret. However, there is an obvious methodological reason why a step-function has not manifested itself in existing research. Consider the rotation increments used in some of the 'rotation' studies -- 60° increments totalling seven data points over 360° (Cooper & Shepard, 1973, 1975; Cooper & Podgorny, 1976), and 45° increments totalling five data points over 180° (Metzler & Shepard, 1974, study three). So few points have been selected that any systematic perturbations would probably go undetected. This suggestion implies that the step function would have revealed itself if a sufficiently small angular increment had been used in the preparation of the stimulus materials. Consequently, an adequate test of this model requires the selection of a greater number of data points and not fewer, which has been the prevalent methodological tendency in the literature.

There are, however, some reasons for supposing that even if more points are selected the step function would still be masked. A consideration of these reasons involves reassessing the assumptions (A2) that the 'rotation' process is the only one that mediates the effect of <u>A</u> on <u>RT</u>, and (A1) that angular disparity is the one stimulus variable relevant to the operation of a 'rotation' process.

<u>Assumption A2</u>

This assumption can be evaluated in light of the eye-fixation data reported by Just and Carpenter (1976). In an

attempt to identify the processes involved in task performance, they analyzed the visual scan paths of subjects engaged in the mental rotation problem, to see how the scan paths varied with the angular disparity of the presented patterns. They made the methodological assumption that the sequence of fixations would more or less correspond to the order in which information in the stimulus is processed. They found that the number and duration of fixations increases as a function of the angular disparity of the two patterns, and that the number of switches between patterns increases as a function of angular disparity.

Just and Carpenter suggested that the data do not argue against the notion of a rotation transformation as such. There is, however, an absence of a step function in Just and Carpenter's response latency data. Just and Carpenter suggested that the entire process of reaching a decision in the experimental task be partitioned into three components: search, transformation and comparison, and confirmation. The second component is what has normally been assumed to be what underlies the slope. That is, it constitutes that system of psychological variables which directly mediates the empirical relation between RT and A, as evidenced in assumption (A2). The first and third components are those psychological activities which correspond to the intercept, and thus should not be affected by angular disparity.

However, the data of Just and Carpenter reveal that each of these components are affected by angular disparity of the patterns. It would seem that the composite RT

reported is in fact a measure of all these processes and not simply -- or even primarily -- of the iterative transformation (i.e., the 'mental rotation'). It is possible, then, that the effect of the independent variable on these other processes serves to mask the detailed structure of the relationship between angular disparity and the one process of interest, the 'rotation' transformation.

But how does one explain the data which seem to indicate that the 'transformation and compare' phase of the process is still more or less linear? One simply has to recognize a slight inconsistency in the interpretation of Just and Carpenter. If the argument is really that "the processor operates on one segment of the figure at a time" (1976, p. 455) then one either has to assume that all the pattern segments or parts are identified in an initial search phase, which is not in accord with the fixation data, or one has to assume that within the 'transformation and compare' phase there is a certain amount of time spent searching for and identifying a new segment. This would suggest that the search process is itself part of the 'transformation and compare' process, and may therefore be masking the step function which should be otherwise predicted from the finite iterative model.

Given the possibility of a number of underlying processes a modification of equation 4 is suggested. One can assume multiple linear components, such that

$$RT = (r/i)A+xA+...+zA \qquad (5)$$

where x...z are an indefinite number of additional

parameters. Continuing the logic which was applied to equation 1, these parameters correspond to processing variables in addition to the 'rotation', such as 'search', 'comparison', or 'confirmation'. This raises an interesting question. Is there any empirical justification in assuming that the measured variation of response latency against one independent variable is providing unequivocal information about a _specific_ process in a conglomerate of activities? Surely, the answer is that there isn't. Even in those cases where an attempt is made to experimentally distinguish the contributions of unique processes to a total response latency, interpretation is still approached with caution (cf. Pachella, 1974). Recognize that the problem is not whether the notion of a 'rotation' process makes sense, but whether a simple linear function can be treated as evidence for its existence. The above considerations imply that it cannot.

Assumption A1

There are two criticisms which can be raised against assumption (A1) that angular disparity is the primary stimulus variable which affects variations in response latency of task performance. The first concerns whether there are other kinds of information which are qualitatively different from that specified in the assumption. The other concerns whether the information specified in the assumption is characterized adequately.

Effects of stimulus structure. There is some indirect evidence which implies that angular disparity is not the

only stimulus variable which has an effect on task performance. The data of Metzler & Shepard (1974) suggested an inverse slope value of 60°/sec. However, other studies have revealed a wide variety of inverse slope values, e.g., 164° to 800° per second (Cooper & Shepard, 1973), and 589° per second (Cooper & Podgorny, 1976). These studies use different stimulus materials which at first glance could account for the slope differences.

There are a few studies, all incorporating a 'rotation' manipulation, which more directly examines a number of distinct ways in which stimulus 'structure' can affect response latencies. Pylyshyn (1979) examined the hypothesis that a process operates on an entire figure, the implication being that the process should not be affected by the structural 'goodness' of the rotated patterns. Rather than pairing patterns with their mirror images, he paired a test pattern with subfigure components of the pattern. The subfigures, and their mirror images were rotated with respect to the test figure, and the subject was required to judge whether the presented subfigure was a part of the test figure. The subfigures varied in terms of their 'goodness' as gestalt-like components of the test pattern. The rationale was that if the 'goodness' of the subfigure affected the slope of the RT function, then this would constitute evidence against a holistic figure rotation model. The anticipated slope changes were obtained; faster rotation rates were implied when the subpattern was 'good'.

Hochberg & Gellman (1977) suggested that unique or

easily recognizable aspects of a pattern could function as landmarks which provide a cue to the orientation of the pattern. By varying the relative inaccessibility of these landmarks, detecting the orientation of the pattern would be more difficult. As a consequence, the slopes of the response latency curves would be steeper. In using the same display procedure as Shepard & Metzler (1971) they showed that the slopes did vary as predicted as a function of landmark cue accessibility.

Yuille & Steiger (1979) also addressed the question of the relationship between figural complexity and reaction time in a mental rotation task. They did not take issue with either the notion of a mental rotation process or the idea that "at some level of complexity this rotation may be holistic" (p. 9). Instead, they examined the capacity of the imagery system with respect to the 'size' of the figure that can be holistically manipulated. They used the Shepard block patterns, but noted that the relevant mirror-image component comprised only a part of the total figure. After showing a set of stimulus figures to subjects, half the subjects were informed that an inspection of the bottom half of the figure was sufficient to solve the task. The procedure was repeated and it was found that the informed subjects' responses improved, i.e., the apparent rotation rate increased. This experiment can basically be viewed as a replication of experiment three in Metzler & Shepard (1974) where they used 7-block patterns and found an increase in apparent rotation rate, which suggested "that mental rotation may be faster

with structurally simpler objects" (p. 180).

The experiment of Just and Carpenter (1976), discussed earlier is also relevant on this point. They found that subjects' eye fixations switched back and forth between the two patterns. Furthermore, the switching is systematic in that the individual sequentially fixates on corresponding parts of the two patterns. Given their methodological assumption, an iterative, holistic transformation of one pattern into the orientation of the other pattern is not suggested by these data. Rather, the transformation operates successively on parts of the overall pattern. This again raises a concern over whether a more detailed account of stimulus structure is required in the present context.

The demonstration of these effects raises some doubts as to the validity of assumption A1. In the continuous rotation model, the only recourse one could take to accomodate effects such as stimulus complexity or familiarity is to assume that these variables affect a non-rotation process. For example, they might affect preparatory time in constructing the to-be-rotated image representation. However, this would only manifest itself in intercept changes. The only other variable explicitly admitted to be involved in the process of determining pattern similarity is the single 'rotation' process which presumably underlies m. To acknowledge that m is affected involves serious compromises with the assumptions which provide the framework of the model. Not only is "rate" not constant (assumption A3), but it also is a function of the properties of the to-

be-rotated stimulus object (assumption A1). The attractiveness of a literal interpretation of the subjective reports is dependent on the simplicity of the model in equation 3. The suggestion that other factors are operating severs the intuitive link between equations 2 and 3 and as a consequence undermines the support which these data provide for a continuous rotation hypothesis.

The finite iterative model is not immediately in trouble, primarily because it already admits to the interpretation of the slope in equation 1 as an index of more than one psychological variable. One way in which these effects could be accounted for within the confines of the linear model suggested in equation 4 would be to hypothesize another variable, $\underline{B}$, which provides an index of pattern complexity. It would seem reasonable to assume that each iteration requires the recreation of the pattern representation at a new angular increment. The more complex pattern requires more time to construct the corresponding representation, and thus the duration of a iteration is increased. Treated as a numerical constant, $\underline{B}$ can be incorporated into equation 4 as

$$RT = (r+B/i)A. \qquad (6.1)$$

Alternatively, complexity might serve to decrease the size of the angular increment which is computed during each iteration. In this case,

$$RT = (r/i-B)A. \qquad (6.2)$$

Finally, the possibility exists that different stimulus qualities have differential effects on different process

variables, as suggested by equation 5. Given stimulus variables C,...,E, we might have

$$RT = (r+B/i)A+xC+...+zE. \qquad (6.3)$$

Such considerations salvage the 'linearity' of the function while at the same time accounting for variations across different stimulus materials. However, the cost is heavy. First, it places considerable theoretical demands on the conceptualization of stimulus structure. In itself, this mitigates against drawing conclusions about cognitive representation from the 'mental rotation' data. Second, the complexity of the equation does not permit easy inferences about the nature of the underlying processes. It is worth repeating that this is not a criticism of the plausibility of a rotation process; it simply indicates the potential difficulty in isolating its unique effect on _RT_, given the methodology as currently employed in the rotation paradigm.

Orientation information. The above criticism of assumption A1 was concerned with whether stimulus properties other than angular disparity had an effect on response latency. That there are is of interest in a broader theoretical context, particularly with respect to cognitive representation. However, the demonstration of these effects is somewhat tangential to an evaluation of the rotation models presented earlier.

The second criticism is more fundamental. This concerns whether the independent variable, characterized as _A_, has been conceptualized adequately. This point is crucial to an assessment of the adequacy of the rotation models. The

rotation hypothesis was developed to account for the relationship between RT and A, and the conceptualization of A determines the nature of the process which operates on it. Specifically, A was viewed as a 'distance'; consequently, the associated process is one which moves or 'rotates' the cognitive representation through this distance.

However, the notion of angular disparity is dependent on a conceptualization of an axis about which the disparity is measured. Given two patterns, there is technically an infinite number of axes about which one pattern can be rotated in an attempt to bring it into congruence with the other. Some sort of co-ordinate system has been implicitly assumed in the rotation models; otherwise, the notion of a 'rotation' about an axis makes no sense.

Some of the complexities which are potentially involved in the processing of orientation information are illustrated in Figure 1. For simplicity, an "L" pattern is considered. Figure 1a presents a stimulus situation as described by Metzler and Shepard, and illustrates two assumptions which were implicitly made. The Metzler-Shepard patterns were "oriented more or less at random prior to rotation...the axis of rotation in this experiment never corresponded to a natural axis of the object itself" (1974, p.153). Here, it is assumed that the subject 'knows' the axis around which the pattern is to be rotated. Although never discussed explicitly, there seems to be the assumption that the gravitational co-ordinate system is used. This assumption is not inappropriate. In this reference frame, the up-down

direction corresponds to the Y-axis, the left-right direction corresponds to the X-axis, and the front-back direction corresponds to the Z-axis. This terminology will be used in subsequent descriptions of stimulus patterns.

Another assumption which seems to have been implicitly made concerns the relationship between the patterns in question and this co-ordinate system. In the development of the <u>finite iterative model</u> (see, e.g., Metzler & Shepard, 1974), a high degree of independence has been assumed. In particular, there is the assumption that the pattern is superimposed on a co-ordinate system. The two classes of information -- figure and orientation -- are treated more or less independently by the processing system. The figure is 'fixed' in the co-ordinate system, and all the intrinsic structural relationships of the pattern are held invariant while the system 'holding' the pattern is rotated. Consequently, a single 180° rotation about the 'upright' (or, in 'depth') is performed.

The second assumption, regarding structure-orientation independence, receives little support from existing research which examines this relationship. There appears to be complex interactions between the orientation of a pattern and the form or structure of the pattern (Rock, 1973). Figure 1b illustrates one alternative. Here, ambiguities regarding the appropriate co-ordinate system to be used can occur when a pattern exhibits a 'natural' orientation relative to an external reference frame. For example, the 'top' of a bottle is still labelled as such even though the

bottle might be inverted. With unfamiliar patterns, such as the block figures, there is not a 'natural' orientation in the sense that the co-ordinate dimensions have specific values such as 'top' or 'front'. However, the structure of the patterns implicitly embodies a three dimensional co-ordinate system.

Some research suggests that under these circumstances judgements of orientation may rely in part on this 'natural' orientation (e.g., Corballis, Zbrodoff, & Roldan, 1976; Massaro, 1973; Palmer, 1980). In this case, the axes of rotation used are those suggested by the structure of the pattern. If 'rotations' are performed in this coordinate field, then two rotations are required to bring the two patterns into congruence. One pattern is first rotated 180° about the 'Y'-axis and then another 90° about the 'Z'-axis.

Figure 1c illustrates another alternative where the figures are 'normalized' with respect to the gravitational co-ordinate system. Some research has demonstrated that the gravitational co-ordinat system exerts a 'normalizing' influence in the perception of tilted or 'oblique' figures (e.g., Attneave & Olson, 1967; Corballis & Roldan, 1975; Corballis, Nagournay, Shetzer, & Stefanatos,Each pattern would first be set in a 'standard' position (assuming that this could be specified unequivocally) and then one pattern is 'rotated' into congruence with the other. In this case, three distinct 'rotations' would be necessary.

The manner in which the patterns were constructed in the Metzler & Shepard studies suggest that these alternative

processes might be functioning. The difficulty is compounded by the manner in which pattern pairs were constructed. From a complete set of patterns rotated at 20° increments around 360°, each member of a pair was chosen more or less at random (A few constraints were employed by Metzler & Shepard). This meant that the internal axes of the patterns were never related in any systematic way to the reference co-ordinate frame which might have been used. As such, the data may not be representative of single axis rotations. In addition, the data make it difficult to determine precisely what information is being used in task performance. Consequently, the nature of the processing involved is ambiguous at best.

This possibility has some bearing on the worth of some additional supporting evidence for the rotation hypothesis. This evidence concerns "the relative lack of dependence of reaction time upon the kind of rotation ('depth' versus 'picture plane') required to bring the two objects into allignment" (Metzler & Shepard, 1974, p.163). It has already been indicated that a consequence of their method of stimulus construction leaves open the possibility that neither the 'depth' (i.e., Y-axis) or 'picture-plane' (i.e., Z-axis) constitutes a singlr axis rotation from the point of view of the subject. There is another source of task variability involving Y-axis (i.e, 'depth') and Z-axis (i.e., 'picture-plane') rotations. Rotation about either of these axes will involve a change in the X-axis direction of the target pattern. The X-axis constitutes the right-left

dimension, and there is evidence that manipulation of this dimension is more difficult for humans than manipulation of either of the other dimensions (e.g., Corballis & Beale, 1976; Loftus, 1978; Maki, Maki, & Marsh, 1977). The similarity of response latency between 'depth' and 'picture plane' is thus not necessarily evidence for a rotation process dependent solely on absolute angular disparity between the two patterns. It may simply be due to their being equally ambiguous regarding the relation of the portrayed patterns to the orientation information necessary for the task judgement.

These considerations have direct relevance for the finite iterative model, in that previous research has rarelyutilized 'single axis' rotations in three-dimensional space. The step function predicted by the finite iterative model might be hidden by virtue of the possibility that the stimulus materials actually required multiple rotations. Another equally plausible consideration is suggested by the data of Just and Carpenter (1976), who showed that visual search increased as a function of angular disparity. They used the stimulus pairs generated by Metzler and Shepard. It is possible that the inherent ambiguity of these patterns regarding axis of rotation and the orientation of the pattern relative to a gravitational co-ordinate system required greater search to establish or define both of these kinds of information.

The following experiment examines these possibilities. Stimuli were constructed such that their axis of rotation

and orientation relative to a gravitational co-ordinate system were unambiguous. In addition, rotation increments of 10° were used. Under these conditions the <u>continuous rotation model</u> should still predict a linear function. If the manipulations are successful in reducing visual search, multiple rotations, and other confusions arising from multiple co-ordinate system comparisons, then a step function should be evidenced according to the expectations of the <u>finite iterative model</u>. Furthermore, two axes of rotation were chosen such that one would exhibit left-right reversals (the Y-axis) and the other would not (the X-axis). Differences in response latencies between these axes would be consistent with the suggestion that absolute angular disparity is not a sufficient characterization of the information requirements of the task.

EXPERIMENT 1

Method

Subjects. The data from twenty-four individuals, selected from the introductory psychology course subject pool, were used for analysis. One participant was dismissed from the experiment because of an apparent failure to perceptually distinguish between a pattern and its mirror image. In addition, the data of four subjects were not used because they seemed unwilling to trust their otherwise rapid judgements with respect to the pattern pairs at a small angular disparity. As one subject verbalized the matter, "it seemed too easy; I thought there might be a trick involved". Finally, five subjects employed task strategies which were very time consuming, and could not complete the full procedure within the allotted time.

Materials and Design. Four patterns, similar to those used by Metzler & Shepard, were defined. Each contained ten blocks and three right-angle joints. The patterns were defined such that the arms of the patterns were always parallel to an axis of the co-ordinate system within which they were constructed. This was considered to be the 'standard' orientation of the pattern. Two patterns were rotated about the Y-axis at 10° increments; this corresponded to Metzler & Shepard's 'depth' condition. The other two patterns were rotated about the X-axis at 10° increments; this rotation preserved the intrinsic left-right structure of the patterns. There is no corresponding set of

patterns among the set used by Metzler & Shepard. Special care was taken to ensure that the axis of rotation corresponded to the appropriate natural axis of the pattern, to prevent multiple axis rotations.

For each pattern a mirror-image was defined such that the 'mirror' was parallel to the plane of the axis around which the pattern would be rotated. This was done to ensure that the mirror-image patterns for the X-axis rotations would preserve the left-right structure of the pattern. Each of the four patterns, in 'standard' position, and their mirror images are illustrated in Figure 2.

Tracings of each of the 152 computer generated patterns were made. The construction of pattern pairs incorporated the white circle on black background format of Metzler and Shepard. The 'standard' orientation of a given pattern was placed in the left circle. Pattern pairs were made by placing in the right circle the corresponding pattern increments, from 0° to 180°, for both same and mirror image patterns. Each pair was photographed, using direct positive, black and white film (Kodak Panatomic-X) and mounted on 35-mm slides. The slides were randomly ordered in two blocks of 76 slides, balanced for same-different, axis of rotation, and angular disparity. Each S was exposed to each slide in a 2(axis of rotation) X 19(angular disparity) repeated measures design.

Procedure. Subjects were introduced to the task requirements in as simple a fashion as possible. They were told that they were to be shown a number of slides on which

they would see two patterns, and that they would be required to decide whether the two patterns were the same as or different from each other. They were then shown a pattern pair, told that the patterns were the 'same', and asked to examine the patterns until they understood how the patterns were the same. Then they were shown a 'different' pair, and again asked to examine the patterns until the nature of the difference was appreciated. The subjects were encouraged to ask questions of clarification; otherwise, the experimenter did not volunteer any information regarding how the task was to be performed.

Subsequent to this, the subject was shown eight more slides (four 'same' and four 'different') and was asked to make the appropriate judgement as to their similarity. Any errors made were pointed out to the subject, and that slide was shown for reexamination.

After the ten practice trials the subject was exposed to the first block of 76 stimulus pairs. An acoustic signal approximately one second prior to the start of a trial prepared the subject for the stimulus presentation. The experimenter pressed a switch which simultaneously opened a shutter and started a timer calibrated to one-hundredths of a second. The S pressed one of two buttons, marked 'same' and 'different', corresponding to his decision of similarity between the two patterns. The depressing of the button simultaneously closed the shutter, stopped the timer, and illuminated a light corresponding to the S's choice on a panel. The experimenter recorded the choice and the response

latency.

After the subject had responded to the first block of 76 stimulus pairs, he was exposed to all those slides to which he had initially responded incorrectly. Although for the purposes of this experiment the response latencies for the 'different' pairs were of no interest, 'different' response errors were also repeated. This was done to insure that the S would not simply respond 'same' by default.

Upon completion of this portion of the procedure the S was allowed to rest for about five minutes. The second block of 76 stimuli were then presented to the S in exactly the same fashion described above. At the conclusion of the experimental procedure the S was questioned generally about strategies used in performing the task.

Results and Discussion

The results of the experiment are illustrated in Figure 3. The plotted points were computed by averaging within each S over the four figures, and then averaging over the 24 Ss. If absolute angular disparity between two patterns was the critical characteristic upon which the psychological process operates, variations in other stimulus attributes should not have had an effect on response latency. As can be seen, the manipulations involving orientation and rotation of the patterns had a novel effect on the relationship between response latency and angular disparity. However, this effect does not correspond to the expectations of either of the rotation models considered in the introduction.

The continuous rotation model should still have

predicted a linear function, assuming that absolute angular disparity was in fact the only relevant stimulus variable. The relationship between angular disparity and response latency in fig. 3 is clearly nonlinear. In fact, an orthogonal polynomial breakdown of this effect revealed significant nonlinear components up to and including the fifth order polynomial (all $p < .01$). Appendix A provides the ANOVA summary table for this analysis. One can appreciate the difficulty in interpreting a higher order polynomial if one views the equation in the same manner as was described in the introduction, e.g., as with equation 6.3. Recall that in equation 1 there was an easy correspondence between the coefficients of the equation and the hypothesized components of the psychological model. In the present experimental situation, there is only one independent variable in terms of which a larger number of coefficients are to be interpreted.

Of course, an explanation of a finding is very much dependent on the way in which the data are described. Additional analyses suggested a more informative description than the higher order polynomial mentioned above. An analysis of the differences among the mean response latencies reveals two interesting characteristics. First, for all <u>adjacent</u> values of angular disparity only the response latencies at the 80° and 90° increments differ significantly ($p < .01$, Duncan's multiple range test). Second, the response latencies from 90° to 180° inclusive do not differ significantly from each other. These findings

suggest a description of the data illustrated in Figure 4. Response latency increases up to 80°. There is a small discontinuity at this point, after which the response latency remains constant with further increases in angular disparity.

This description does not conform to what can easily be described as a step-function relationship between angular disparity and response latency, as would be predicted by the finite iterative model. It is possible, for example, that the 'flat' region between 90° and 180° constitutes one such step. However, there remains the problem of accouting for why there is not a step between 0° and 90°. Alternatively, one might want to continue to argue, as was done in the introduction, that this relationship is 'hidden' by other confounding variables, or that an insufficient number of points were sampled. However true this might be, it is nonetheless the case that a 'flat' region has already been determined.

The main finding of a nonlinear relationship between response latency and angular disparity in the presence of a 'standard' pattern serves to mitigate against assumption A1 of the rotation models considered earlier. In addition, the results of Experiment 1 indicate that it is easier to respond to X-axis than to Y-axis rotations, $F(1,23) = 18.99$, $p < 0.001$. This provides further evidence that orientation information, and not simply angular disparity, is being used. This finding is consistent with previous research which indicates that humans have some difficulty working

with left-right reversals. It is also consistent with the claim that absence of axis of rotation differences in previous research was due to a failure to properly isolate single axis rotations. An interpretation of these findings are complicated by the presence of an Axis X Disparity interaction, $F(18,414) = 3.30$, $p < .001$. Appendix A, table 2, provides the cell means and standard deviations for this interaction. In addition, the data suggested that Ss' responses might also be interacting with both axis of rotation and angular disparity. An inspection of the raw data did not reveal an obvious pattern to these differences.

In view of this, a cluster analysis was performed to determine if there were groupings in the data which did not correspond to the variable partitioning in the experimental design. The responses of each S to each individual pattern was treated as a separate case. Each angular disparity from 0° to 180° was treated as a separate within case variable. This resulted in 96 cases (24 Ss by 4 patterns) which were subjected to a hierarchic fusion clustering procedure provided by Wishart (1978), utilizing a minimum-variance similarity criterion. The procedure begins with each case defined as a separate cluster, and on each fusion cycle the two clusters whose fusion yields the least increase in the error sum of squares are combined.

The dendrogram produced by this procedure is illustrated in Figure 5. For present purposes, a two cluster interpretation will be considered for further discussion. The mean response latencies at each angular disparity,

averaged across the cases in each cluster are presented in Fig. 6.

Examination of the differences among means within each cluster revealed a pattern similar to that described previously. In the slow response cluster, the only significantly different adjacent response latencies are those at the 80° and 90° increments ($p < .01$). Again, all response latencies between 90° and 180° inclusive do not differ significantly. In the fast response cluster, the significantly different adjacent means are those at 70° and 80° ($p < .01$), and all means between 80° and 180° do not differ significantly. Figure 7 illustrates this description.

An examination of the cases captured within each cluster reveals an interesting trend. The 'fast' cluster included 43 cases. Of these, 28 cases comprised the responses to all patterns by seven individuals. Of the remaning fifteen cases, twelve of them were to patterns which had been rotated around the X-axis. Of these, ten cases comprised the responses of five Ss to both X-axis patterns. The 'slow' cluster captured the remaining 53 cases, which included the total responses of ten individuals (40 cases). Of the remaining thirteen cases, eleven of them comprised responses to patterns which had been rotated around the Y-axis. Eight of these were the Y-axis responses of four individuals.

It is misleading to conclude that the two clusters illustrated in Fig. 7 represent two types of responders. The cluster contents actually suggest three types of responders.

There are two types who respond in a characteristically slow or rapid fashion independent of axis of rotation. In addition, there is a third type which seems to be more strongly affected by axis of rotation. They respond more quickly to X-axis than to Y-axis rotations. Finally, it should be kept in mind that responses of about one third of the original sample were not included in the analysis. These individuals might be presumed to exhibit a unique response pattern of their own.

The finding of large between-subject differences should not be surprising. The extent to which these differences are due to performance strategy preferences and to differing abilities in perceiving and structuring spatial relationships is not clear. However, the bias would seem to be towards the latter (Vandenberg, 1969), a conclusion which is supported by the between-subject response differences to axis of rotation.

In sum, the data support the suggestion that task performance depends much more on the perception and processing of orientation information than has been supposed by the 'rotation' hypothesis. The suggested effect of using a pattern in a 'standard' orientation was that it would make not only the axis of rotation but also the relation of the pattern to the relevant co-ordinate frame salient to the perceiver. The information, being more accessible, would have the effect of reducing that aspect of response latency due to such factors as search and relating gravitational and pattern induced co-ordinate reference frames.

If this is in fact the case, then eliminating a 'standard' from the pattern pairs should serve to force additional stimulus processing. To test this idea, a new set of stimuli were prepared. Both members of a pair were chosen so as to minimize the extent to which the pattern arms were alligned with a gravitational co-ordinate frame. The one exception, of course, is the arm (or arms) parallel to the axis of rotation. If subjects' must in fact devote some processing time to defining orientation, then a linear relationship between RT and A should emerge.

EXPERIMENT 2

Method

Subjects. The data of twelve individuals selected from the introductory psychology course subject pool were retained for analysis. Seven Ss did not complete the experimental session for reasons similar to those given in the first experiment.

Materials and design. Two sets of stimuli were prepared. For expository convenience, the first set shall be called the control set. These comprised the stimulus slides which had been prepared for the first study. However, the stimulus pairs at 20° increments only were selected, resulting in a total of ten 'same' pairs per pattern. The corresponding 'different' pairs were included, making a total of eighty pattern pairs in the control set.

For the second set of stimuli, called the Metzler-Shepard set, new stimulus slides had to be prepared. The pattern tracings used in the first experiment were again used. The difference was that the 'standard' orientation was no longer in the left circle of the stimulus mask. Instead, patterns were selected for each member of a pair to maximize an oblique orientation of the arms. As the original set of patterns included increments within a range of 180°, in contrast to the Metzler-Shepard stimuli which included increments through a full 360°, three additional increments were generated for each pattern between 180° and 270° from the 0° orientation of the pattern. This allowed for the

construction of pattern pairs -- primarily at greater angular disparities -- which included the 'oblique arm' criterion. A mirror-image pattern was constructed at each angular disparity for each pattern, making a total of eighty pattern pairs in the Metzler-Shepard set. An example of a control pair and a Metzler-Shepard pair are shown in Figure 8.

The patterns were randomly arranged into two blocks of 80 slides, balanced for an equal number of exposures to each angular increment. Each S was exposed to all pattern pairs in a 2 (stimulus set) X 10 (angular disparity) repeated measures design.

Procedure. The procedure used in Experiment 1 was followed exactly. Of special note is the fact that Ss were not told that they were about to view (according to the experimenter's criterion) two sets of patterns. They were simply told that they were about to view a number of pattern pairs and were to make the required similarity judgement.

Results and Discussion

In general, response latencies exhibited a higher intra-individual variability. Subjects were more inclined to state that the task was difficult, and this was reflected in at least one response being noticably longer than the others. Because of this, the median response latencies for each subject at each angular disparity were computed. An analysis of variance was performed on these data. Appendix B provides the ANOVA summary table and the cell means and standard deviations of this analysis. Of primary interest

here was the significant Stimulus Set X Angular Disparity interaction, $F(9,99) = 7.68$, $p < .001$. These data are illustrated in Figure 9. It can be seen that the results of the first experiment were replicated. In addition, the Metzler-Shepard stimulus set yielded a response latency curve which corresponds closely to the traditional increasing linear function.

These findings show that the presence of a 'standard' pattern reduces the response latencies of the judgements of similarity. The most dramatic difference between the two response curves is at angular disparities greater than 90°. This suggests that whatever information is made accessible to the perceiver by the 'standard' pattern, it is used primarily at the greater angular disparities.

An interesting correspondence can be noted between these data and the data of Just and Carpenter (1976). Recall that their response latencies were linear up to about 100°, after which the curves accelerated positively. As they used the original stimulus materials of Metzler & Shepard, there was not only an absence of a 'standard' but the patterns were also not alligned with the rotating co-ordinate system. It may be that this latter factor creates additional task difficulty (as described in the introduction) which is reflected in the positively accelerated curve. Both sets of data can thus be viewed as being consistent with the notion that disparities greater than 90° require explicit use of the sort of information which the presence of a 'standard' provides.

It is important to note that the effect of the 'standard' cannot be simply ascribed to effects such as familiarity or learning; e.g., that the presence of a 'standard' allows the subject to more easily define the relationship between the pattern and a co-ordinate reference frame. As a within-subjects design was used, this explanation would still have to account for why this information could only be used in the presence of a 'standard'. This suggests strongly that it is the characteristics of the stimulus display itself which is largely determining the behavior.

The possibility, then, is that certain characteristics of the stimulus array predispose the perceiver to process it in certain ways. The fact that the presence of a 'standard' did not appreciably alter the shape of the response latency curve below 90° suggests that a strategy such as was illustrated in Fig. 1b may be operative. That is, the co-ordinate system as implied by the orientation of the pattern is used in task performance. At disparities greater than 90° explicit reference must be made to an independently defined co-ordinate reference frame, specifically, the gravitational co-ordinate frame. A strategy such as was illustrated in Fig. 1c may be in effect, where the patterns are 'normalized'. That is, the relationship between a pattern and the gravitational co-ordinate system must be specified. If this relationship is already provided by the presence of a 'standard', then less processing of the stimuli is required.

This account will be expanded shortly; for now, the conclusions to be drawn from this study will be stated in a general form. The results replicate those of experiment one and support the claim that task performance depends in important ways on gravitationally defined orientation information. The results also support the suggestion that previously found linear relationships are a consequence of processing requirements induced by the absence of explicit pattern-orientation information. Contrary to the assumptions which underly the rotation models defined in the introduction, more than one type of information is used in task performance. Furthermore, different kinds of information in the stimulus display seem to induce different processing strategies.

GENERAL DISCUSSION

The first question which this study addressed was whether existing data can reasonably be supposed to support the 'rotation' hypothesis. The nature of this support is reflected in three assumptions which underly the interpretation of the data.

First, assumption A1 has not been supported. The presence of response latency differences between different axes of rotation and the beneficial effect of a 'standard' indicate that absolute angular disparity is an insufficient characterization of the information utilized in task performance. If the evidence of the 'flat' region between 90° and 180° is to be taken literally, then angular disparity has no effect whatsoever at those disparities. Second, with the unique functional status of angular disparity in doubt, assumption A2 is by implication of questionable validity. It is conceivable that a 'rotation' mediates the effect of angular disparity on response latency. However, if angular disparity is of minimal functional significance, then so is the notion of a 'rotation' as an account of task performance. Third, assumption A3, regarding the linear relationship between response latency and angular disparity is clearly disconfirmed.

In short, the quantitative basis for the rotation models has not been confirmed by the two experiments reported here. What has to be stressed is that the line of

reasoning which linked a set of data to a specific hypothesis is broken. This does not in itself invalidate the 'rotation' hypothesis. However, the prudent conclusion to be drawn is that existing data collected within the 'rotation' paradigm cannot be viewed as supporting the notion of a rotation process. Furthermore, the support which this research provides for broader claims about cognitive representation and processes is equally doubtful.

Reinterpreting Subjective Experience

We are now in a position to examine the other question which concerns this dissertation. Is there any reason for assuming, a priori, a 'rotation' process as a working hypothesis? It has already been shown that the quantitative basis of a rotation process is not secure. The qualitative data, i.e., the introspective reports of task performance by subjects in the present experiments, also do not strongly predispose one to assume the existence of a 'rotation' process.

Among those subjects whose data were retained for analysis, the phrase "rotating one pattern into the other" was only occasionally used as an initial description of their activity. The locution "trying to fit one pattern on top of the other" was much more common. When asked how this fit was accompished, responses such as "fitting one part to the other" and "turning one of the patterns around" were used with equal frequency, and not uncommonly by the same subject. The point here is not simply a matter of a lack of consensus among individuals regarding their verbal

descriptions of a mental event. What is interesting is the contrast between this lack of consensus regarding task performance and the relatively high degree of agreement that a sense of phenomenal movement accompanied task performance.

It was suggested in the introduction that the reported 'movement' was used as a bridge to a physical analogy, from which the psychological models were derived directly. If the psychologically felt 'movement' is the phenomenon which requires explanation, then rather than drawing analogies to physical events, a more productive strategy might be to consider parallels to other instances of phenomenal movement, such as stroboscopic, or apparent, perceptual motion. The phenomenon seems to be quite common across a number of sensory modalities. Visually, there are such mundane phenomena as the apparent motion of marquee lights or motion pictures. Acoustically, there is the stereophonic effect of motion.

The pervasiveness of the subjective movement experience in a variety of contexts and sensory modalities suggests that its significance does not lie in an implied 'rotation' or some other 'movement' of a representation. Kolers (1972) was of the opinion that the experience reflected, in part, the highly synthetic processing quality of the perceptual system. The system is presented with two successive stimulus patterns and fuses them in an attempt to resolve discrepancies. The process of fusion is experienced as motion (or a number of other plastic deformations).

The notion of a 'fusion' can perhaps be more easily

appreciated by considering the effect of a simple stereoscope. Here, the disparities between two unique stimuli are resolved into a single perceptual event. The resolution of the disparity is experienced as stereoscopic 'depth'. Analogously, with stroboscopic phenomena, the resolution of disparate stimuli is experienced as 'movement'. The analogy to the present paradigm is that the individual is again presented with two patterns. A representation of one pattern (or a part of it) is compared to the representation of the other. This process of comparison is also experienced as movement. This account is in accord with the eye fixation data of Just & Carpenter. The successive scanning in some sense corresponds to the successive stimulus presentations in the typical apparent movement paradigm. However, no increments are created; or, to put it another way, the 'increments' are as large as the angular disparity present in the pattern.

The appeal of this interpretation is that it interrelates a wider range of psychological phenomena than does the notion of a 'rotation'. It is also consistent with subjects' ability to clearly distinguish between the phenomenally distinguished movement as such, and the ambiguous relationship which this affords to a process by which task performance is executed.

An Alternative Model of Task Performance

Some alternatives to the 'rotation' hypothesis shall now be considered for the present results. In particular, some understanding is required of why the presence of a

'standard' resulted in a flat function at angular disparities greater than 90° while its absence resulted in an increasing function. Furthermore, some account must be given of why the presence versus absence of a 'standard' did not result in response latency differences at disparities greater than 90°.

It is first assumed that the stimulus display used in the present experiments is multidimensional and that the means by which the display is processed is sensitive to the multidimensionality. The dimensional attributes include such factors as number of blocks per pattern, retinal projection, orientation relative to a gravitational co-ordinate frame, and angular disparity between the two patterns.

In addition, it is assumed that subsets of attributes can be processed either integrally or separately (e.g., Garner, 1974; Smith & Kemler, 1978; Triesman, Sykes, & Gelade, 1977). As an illustration of this distinction, consider the following. If a person were to look at one of the stimulus figures used in the present experiments, most of the time he would describe it as being a picture of a three dimensional object. In the present experimental task, the drawings are in fact treated as such. On the other hand, the drawing can be described as being a set of lines or a set of squares, trapezoids, etc. In some sense, the pattern doesn't exist independent of the numerous separate lines which comprise it. However, these attributes are processed integratively when the pattern is treated as a three-dimensional object. Alternatively, a person could just as

easily perform a task relevant to this information, such as counting the lines or surfaces, or even counting the lines which are 'hidden' from view in the three dimensional object. In this case these attributes would be processed separately, or disjunctively. Similarly, it is assumed that attributes of orientation can be treated either integrally with or separately from other stimulus attributes.

It has also been found useful to postulate at least two stages in models of visual search. These are commonly characterized as an initial, global analytic stage and a subsequent stage involved in more detailed analyses (e.g., Hoffman, 1978; Neisser, 1967; Shiffrin & Schneider, 1977). The initial processing serves a variety of functions, including selection of specific strategies to be employed by subsequent search stages (Corcoran & Jackson, 1977) and the 'chunking' of the stimulus display into parts for further analysis (Bartram, 1978).

In the present task situation, it is suggested that the preprocessor makes an initial determination of orientation similarity based on global features. For example, the analysis might determine if both patterns have an upward pointing arm on the left side. In addition, an estimate of pattern similarity is made based on other attributes, such as perimeter shape, surface area, or location of distinctive features. This index of similarity is used as a basis for selecting subsequent, more detailed analyses. Of course, it is possible that an actual decision regarding pattern similarity can be made at this initial stage of processing.

It is suggestive that the results of experiment one evidence a small, but statistically nonsignificant, discontinuity at 20° angular disparity. This might mark the range of acceptable 'similarity' for the initial stage of processing.

Within a given threshold of 'similarity', a more detailed sequential analysis is performed. As suggested by Bartram (1978), the pattern is analyzed in chunks. The implication is that the size of the chunks will be determined by the initial estimate of similarity. A low estimate of similarity requires a finer grain of chunking; finer grains require more frequent sampling of the patterns. This implies that there will be a greater number of fixations within patterns and more frequent switching between patterns. This has been shown to be the case (Just & Carpenter, 1976). In addition, other evidence supports this hypothesized relationship between frequency of fixations and 'integrality' of the stimulus display. Relatively fewer fixations of a stimulus display imply more efficient use of the visual periphery which in turn implies greater stimulus organization, or attribute integrality (Goolkasian & Bunt, 1978; Locher & Nodine, 1973; Rayner, 1978).

By this account, the increasing linear function up to about 80° is not due to a 'rotation' through an angular distance at a constant rate. Rather, it is due to the degree of detailed analysis required of the patterns. Angular disparity between the two patterns contributes to their general estimate of similarity. As such, it is correlated with increases in response latency, but otherwise does not

play a unique role in the processing of the patterns.

On the other hand, analysis by the preprocessor may determine that the patterns exceed some acceptable threshold of similarity. As orientation comprises the critical attribute under consideration, this threshold may be reflected in global qualities such as arms on the same side of the two patterns pointed in different directions. It is suggested that exceeding this threshold results in a change in the attribute structure. Orientation and form must now be processed in a differentiated -- in contrast to an integrated -- fashion. For the two patterns to be meaningfully compared a common basis of comparison must be established. That is, the orientations of the patterns are to be judged same or different relative to some shared criterion. Existing evidence suggests that this basis is the gravitational co-ordinate system.

The presence of a 'standard' provides for the physical presence of the attributes of gravitational orientation within the structure of the pattern. The attributes must still be processed disjunctively, however. This will serve to increase memory load, and consequently, processing time. It would seem reasonable to assume that chunking size, as manifested in number of fixations, will have reached an efficient lower limit. As a consequence, the number and duration of fixations, and the number of switches would be more or less constant. This will result in a relatively flat response latency function past the global similarity threshold. The data suggests that this threshold is reached

around 90°.

On the other hand, the absence of a 'standard' eliminates some of the attributes which cue gravitational orientation in the display. The subject is required to interpret the orientation of the patterns on the basis of internally represented attributes a gravitational co-ordinate system. This can have a number of obvious effects on response latency.

As was suggested in the introduction, the actual comparision of the patterns should not in itself be affected by the absence of information provided by the 'standard'. Rather, other processes are affected. One candidate suggested by the Just and Carpenter data was search time involved in matching corresponding segments of the two patterns. The possible effect of a 'standard' is to provide a stable external framework for estimating the location of a pattern segment; consistent with the evidence on visual scanning, this would be accomplished by the visual periphery selecting potential locations for subsequent fixations.

A second alternative, also consistent with the above point, was suggested by Treisman (1977). She found that in speeded search conditions the narrowing of attention (i.e., sampling smaller chunks) varies as a function of the physical presence vs. presence in menory of attributes of multidimensional stimuli. In being forced to rely on memory in the 'standard absent' condition, more stimulus samplings are required; consequently, response latency increases.

Summary

It might appear that an unusually large number of hypotheses have been invoked to account for relatively few findings. In fact, two general assumptions have been made. First, that the stimuli used in the present experiments are functionally multidimensional. This assumption is made in contrast to assumption A1 of the rotation models, which postulated only angular disparity as functionally relevant. The results of the present experiments forced the abandonment of that assumption. Furthermore, assuming multidimensionality is consistent with a much wider range of research and psychological problems than is the assumption of the 'rotation' models.

The second assumption that was made concerned the presence of multiple visual search and comparison strategies or stages which can be differentially activated as a function of the stimulus display and task requirements. This assumption is also strongly supported by existing research on problems of visual search. In contrast, assumption A2 of the rotation models postulated one relevant process, the 'rotation'. The results of the present experiments suggested that this assumption is also untenable.

Unfortunately, both of these assumptions do not make for parsimonious accounts of particular findings. However, there are some virtues in holding to these assumptions. They serve, initially, to place the phenomenon of 'mental rotation' in a more realistic perspective relative to other research and other theoretical positions within psychology.

The value of the explanatory framework outlined above is that it provides a link among fields of research including visual search and attention, eye scanning, and even phenomenal movement.

More important, however, is the point that the above account places emphasis on stimulus structure and organization. The current imagery-proposition debate notwithstanding, it has long been clear that the notion of 'structure' is an important consideration in problems of perception (see Allport, 1955; Garner, 1974; Palmer, 1978; and Reed, 1978, for various perspectives). Furthermore, as the above account attempted to demonstrate, the notion of 'holistic' processing is not inconsistent with concerns for stimulus structure and its representation. In fact, the notion of holistic processing, once recognized as a variable quantity, is dependent on a theory of structure. This notion has been illustrated by conceptions such as variable cunking size and the distinction between attribute integrality and attribute separability.

A theory of structure requires a conceptualization of those attributes being structurally interrelated. The results of the present study have advanced beyond previous research on 'mental rotation' by demonstrating the importance of orientation information in task performance. Finally, by framing an explanation of these results in terms of the functional interrelationships of stimulus attributes, future examinations of the validity of these hypotheses will be examining problems of structure which are central to an

understanding of cognitive representation.

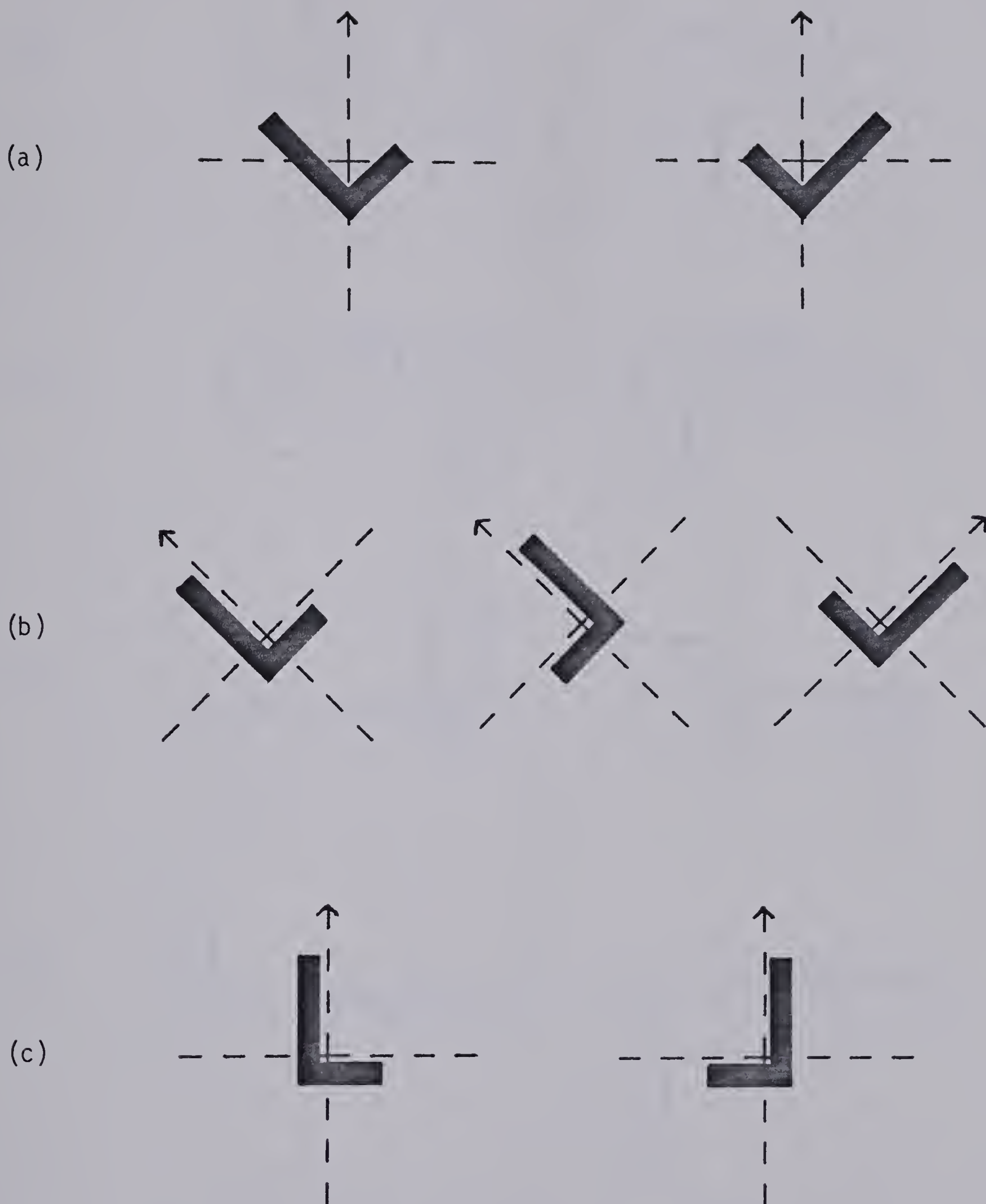

Fig. 1. Three alternative ways of relating structural and orientation information. See text for explanations.

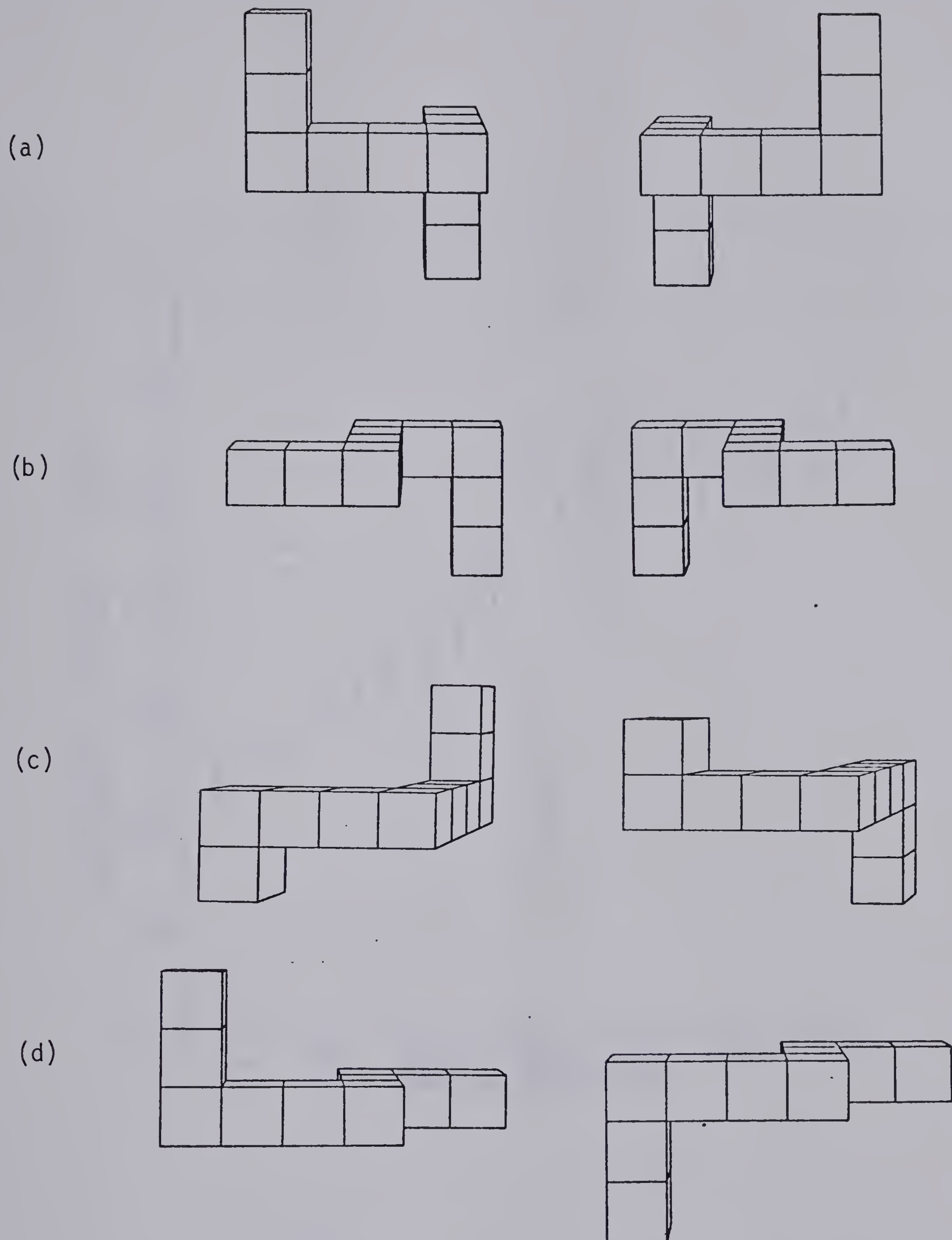

Fig. 2. The four patterns, and their mirror images, used in experiment 1. Pairs (a) and (b) were rotated about the Y-axis. Pairs (c) and (d) were rotated about the X-axis.

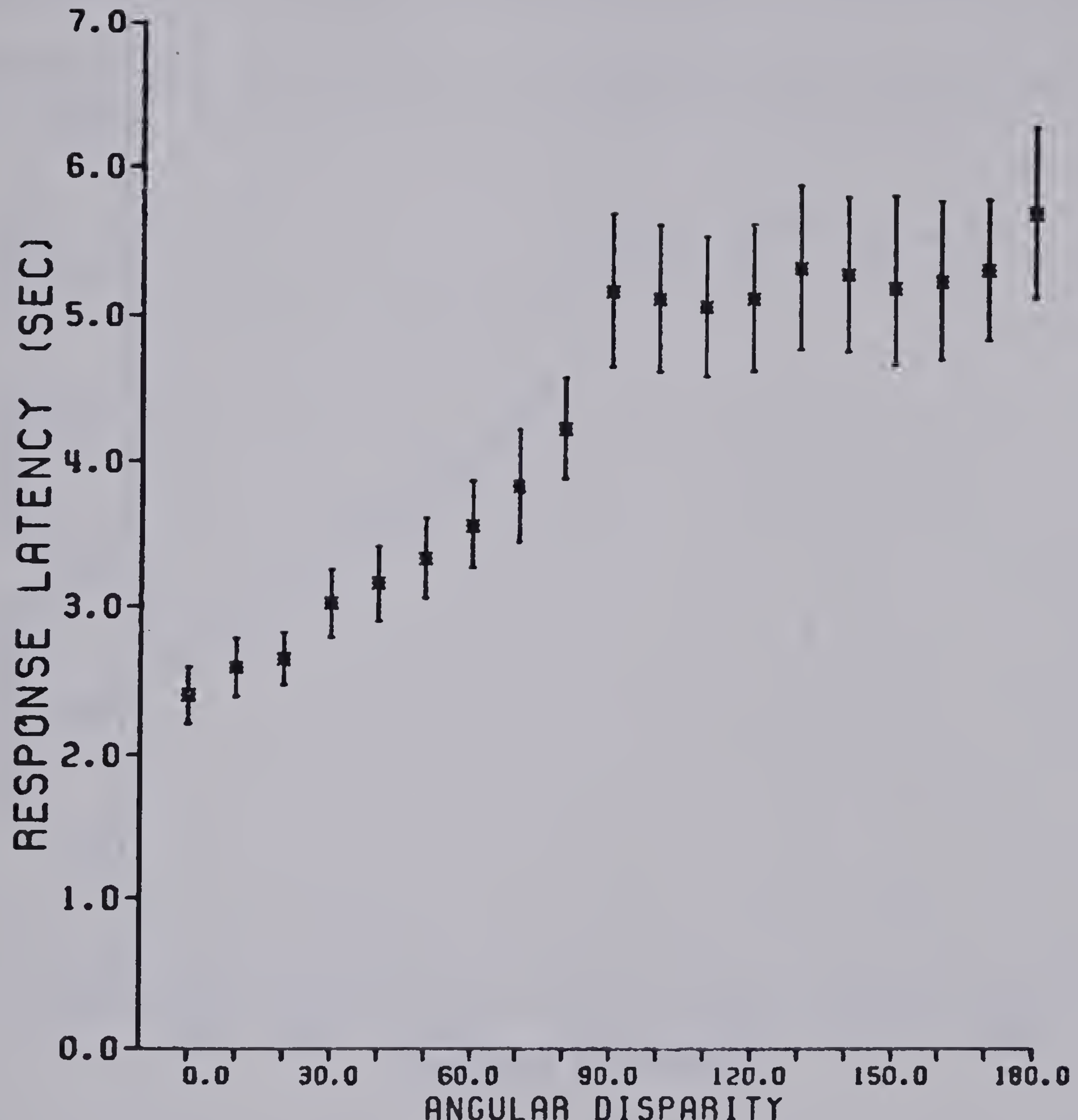

Fig. 3. Mean response latencies plotted against angular disparity: Experiment 1. Vertical lines are standard errors.

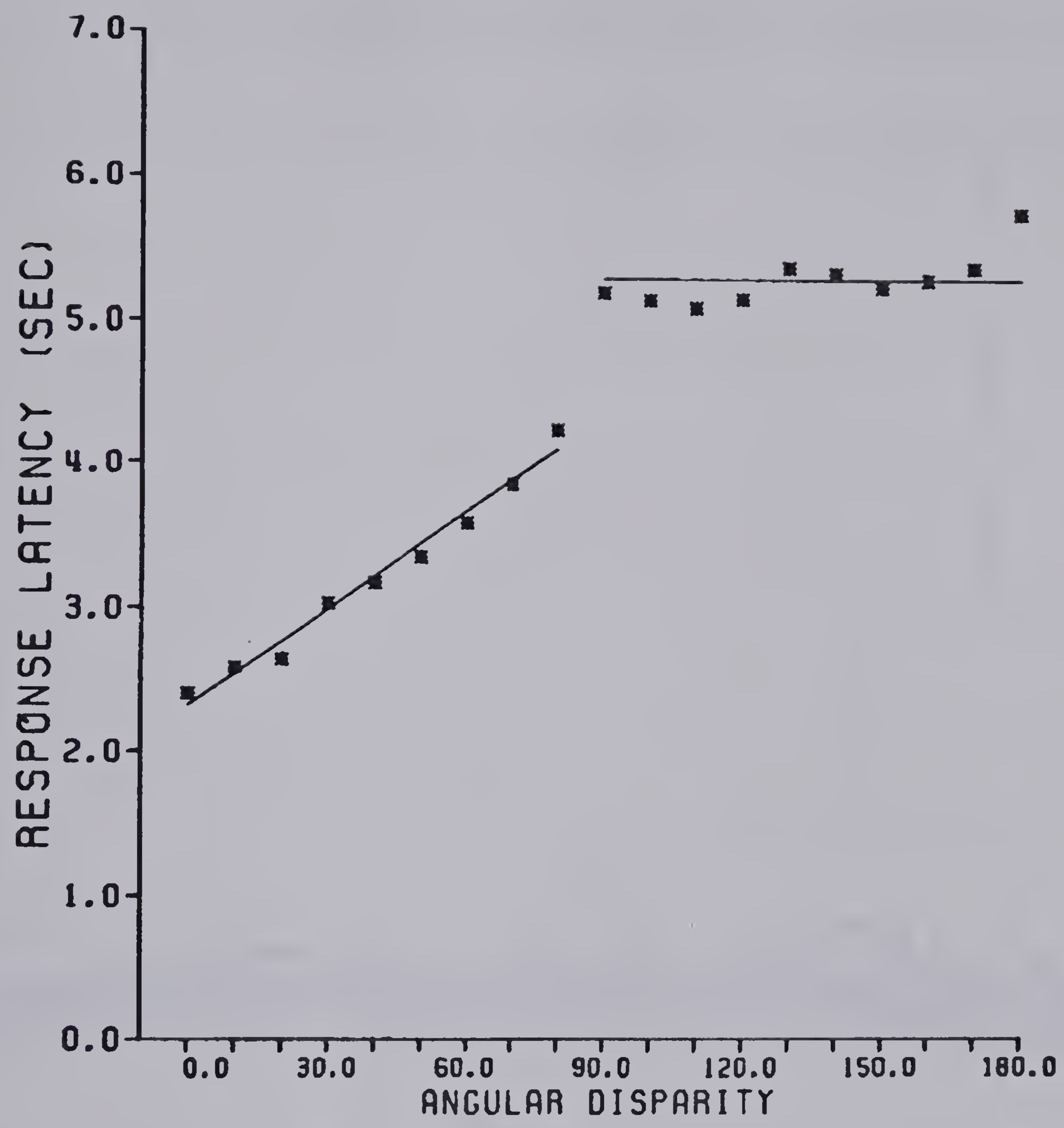

Fig. 4. Suggested description of response latency data: Experiment 1.

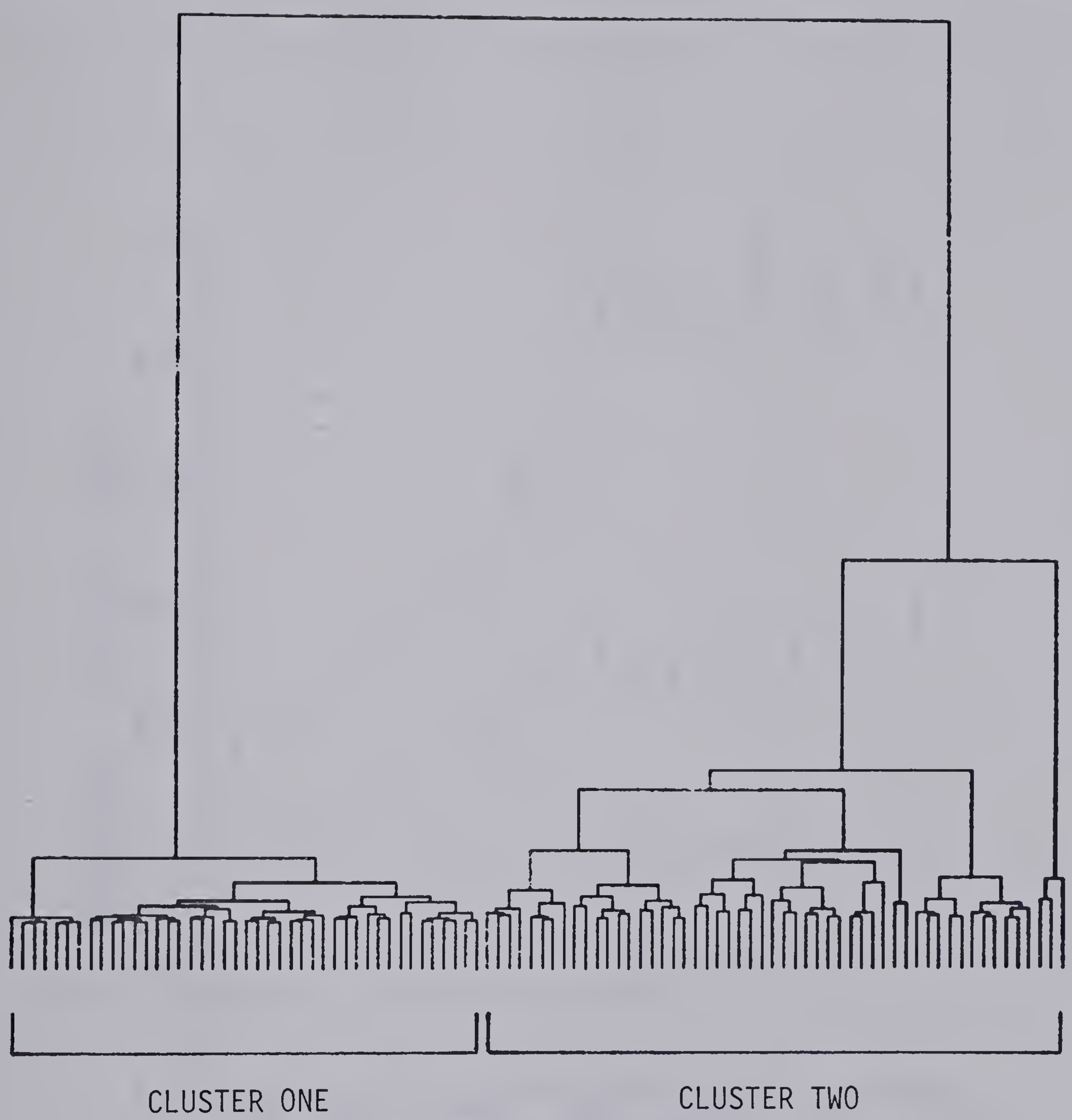

Fig. 5. Dendrogram produced by cluster analysis of response latency data. Vertical scale represents relative increase in within-cluster variance at a given cluster fusion point.

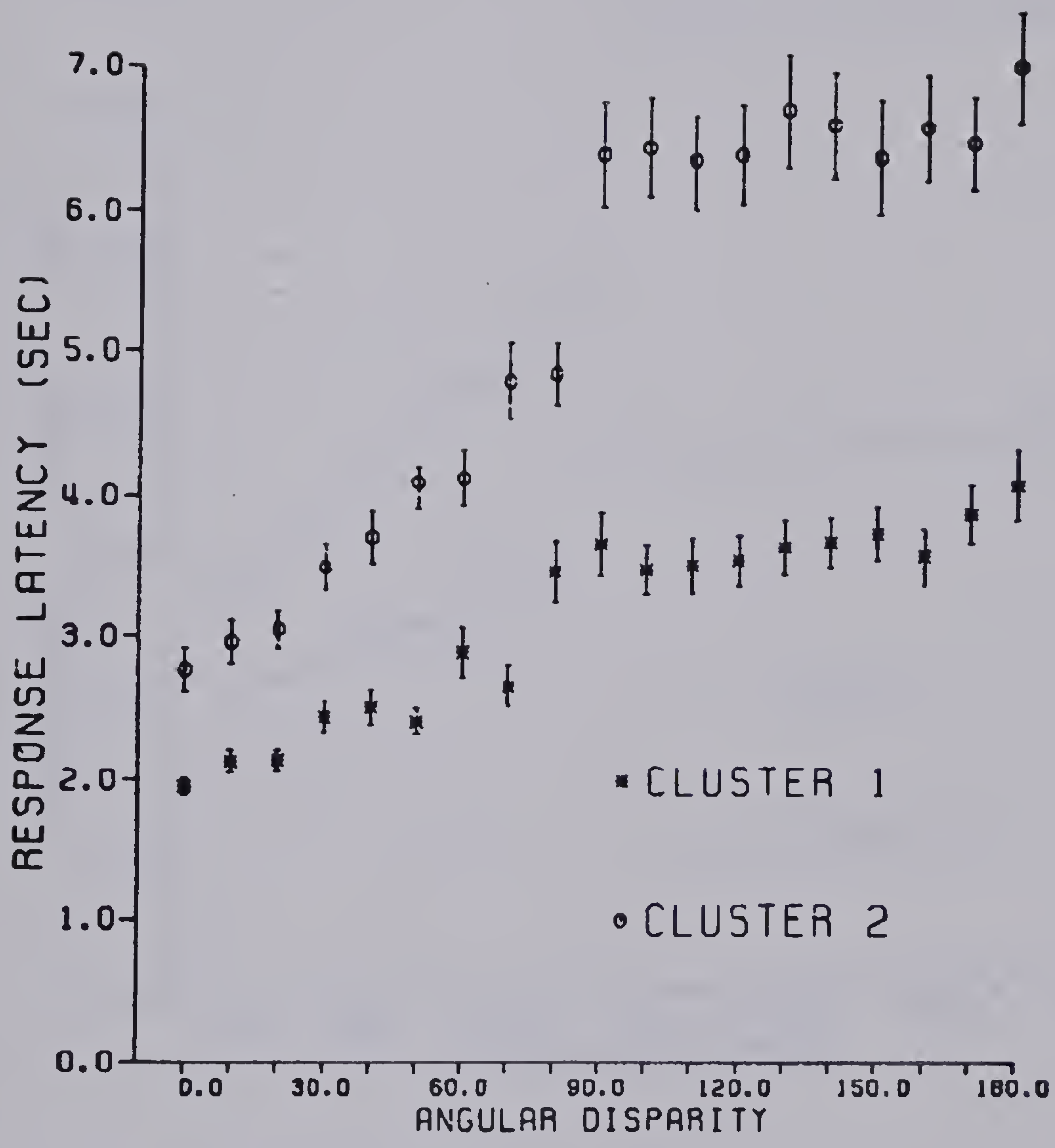

Fig. 6. Mean response latencies plotted against angular disparity for the two cluster solution. Vertical lines are standard errors.

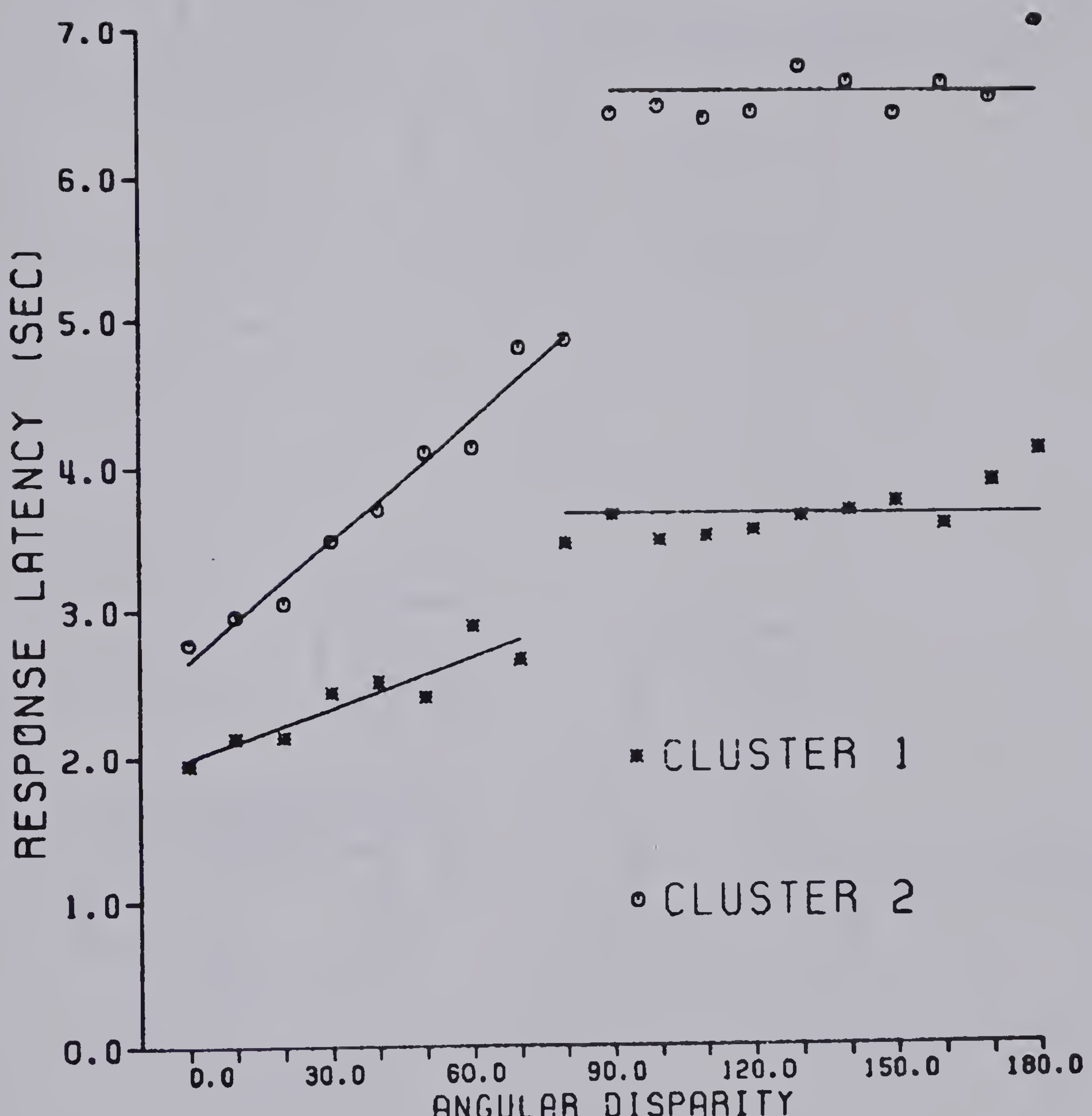

Fig. 7. Suggested description of the two cluster solution.

(a)

(b)

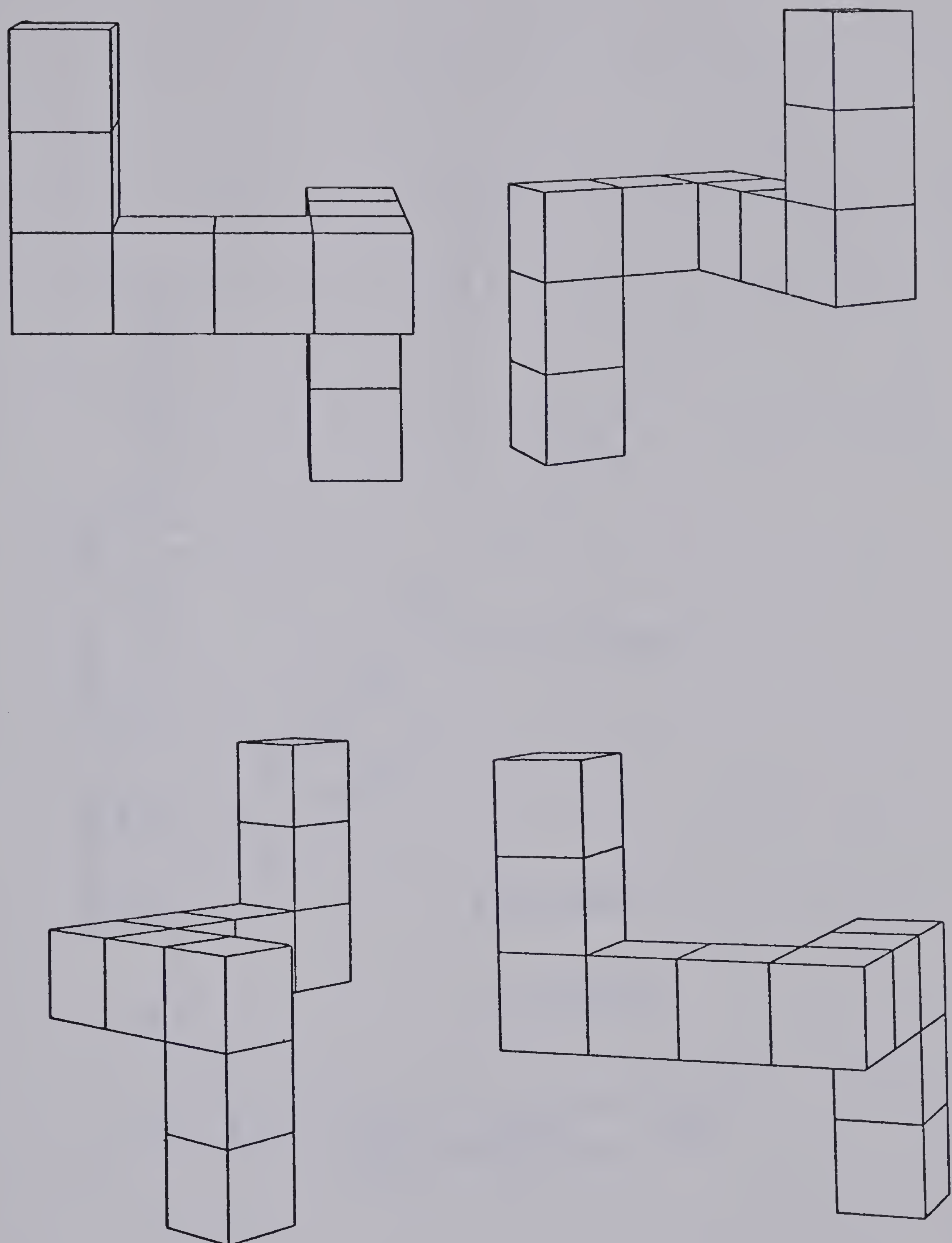

Fig. 8. Examples of stimulus pairs used in experiment 2. Pair (a) is an example of a 'standard' set. Pair (b) is an example of a 'Metzler-Shepard' set.

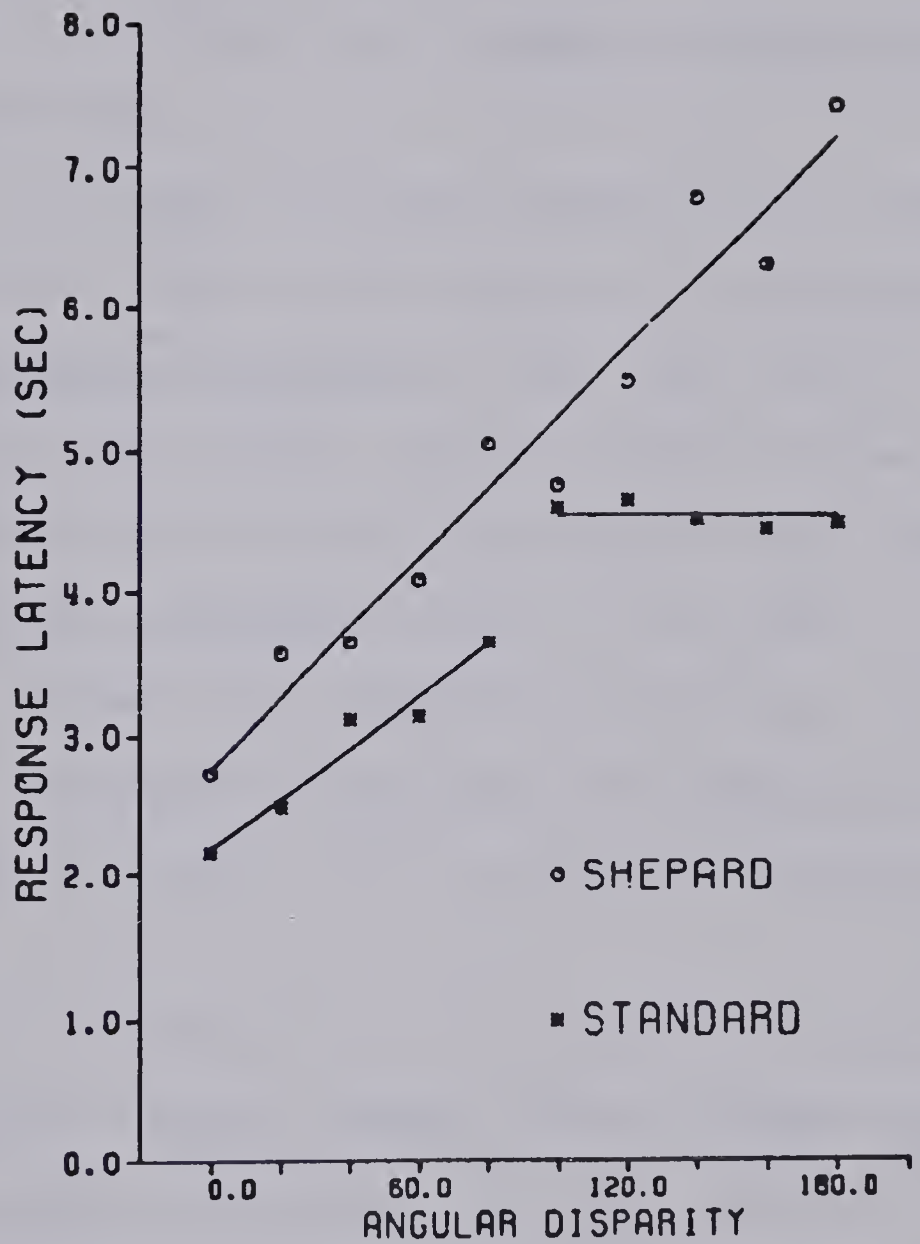

Fig. 9. Mean response latencies plotted against angular disparity: Experiment 2.

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APPENDIX A

TABLE 1: ANOVA summary for experiment 1

SOURCE	SS	df	MS	F	p
AXIS: A	72.17	1	72.17	18.99	.001
S(A)	87.43	23	3.80		
ANGULAR DISP: B	1142.99	18	63.50	42.44	.001
S(B)	699.44	414	1.50		
LINEAR: B	1032.40	1	1032.99	136.51	.001
error	173.95	23	7.56		
QUADRATIC: B	52.74	1	52.74	28.21	.001
error	43.01	23	1.87		
CUBIC: B	11.76	1	11.76	13.56	.001
error	19.95	23	0.87		
QUARTIC: B	17.65	1	17.65	10.30	.004
error	39.40	23	1.71		
QUINTIC: B	10.23	1	10.23	8.61	.007
error	27.31	23	1.19		
A x B	63.53	18	3.53	3.30	.001
S(AB)	442.17	414	1.07		

TABLE 2: Cell means and standard deviations

	Y-AXIS		X-AXIS	
Ang. Disp.	mean	s.d.	mean	s.d.
0	2.337	0.790	2.470	0.835
10	2.678	0.895	2.499	0.840
20	2.578	0.751	2.713	0.752
30	2.939	1.050	3.113	.901
40	3.262	1.141	3.084	1.049
50	3.601	1.201	3.104	1.138
60	3.494	1.120	3.669	1.059
70	4.290	1.804	3.412	1.232
80	4.455	1.481	4.022	1.175
90	5.664	2.041	4.713	2.052
100	5.579	2.354	4.696	2.071
110	5.778	2.078	4.411	1.769
120	5.779	2.473	4.516	1.509
130	5.709	2.420	5.017	2.140
140	5.503	2.200	5.141	2.184
150	5.912	2.827	4.541	1.435
160	5.334	2.658	5.219	1.796
170	5.869	1.889	4.841	1.421
180	6.304	2.582	5.191	2.015

APPENDIX B

TABLE 1: ANOVA summary for experiment 2

SOURCE	SS	df	MS	F	p
STIMULUS TYPE: A	95.64	1	95.64	126.47	.001
S(A)	8.32	11	0.76		
ANGULAR DISP: B	312.32	9	34.70	35.52	.001
S(B)	96.72	99	0.98		
A x B	40.67	9	4.519	7.68	.001
S(AB)	58.29	99	0.59		

TABLE 2: Cell means and standard deviations

	STANDARD		SHEPARD	
Ang. Disp.	mean	s.d.	mean	s.d.
0	2.156	0.682	2.739	1.181
20	2.491	0.847	3.560	1.366
40	3.123	1.284	3.640	0.986
60	3.139	1.161	4.091	1.421
80	3.640	1.297	5.063	1.707
100	4.610	1.801	4.779	1.628
120	4.670	1.938	5.492	1.713
140	4.534	1.962	6.809	2.580
160	4.459	1.622	6.340	2.208
180	4.513	1.728	7.450	3.114